

*Presentation at the
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High Penetration of Wind Energy into Island Diesel Grids Experience from Cape Verde

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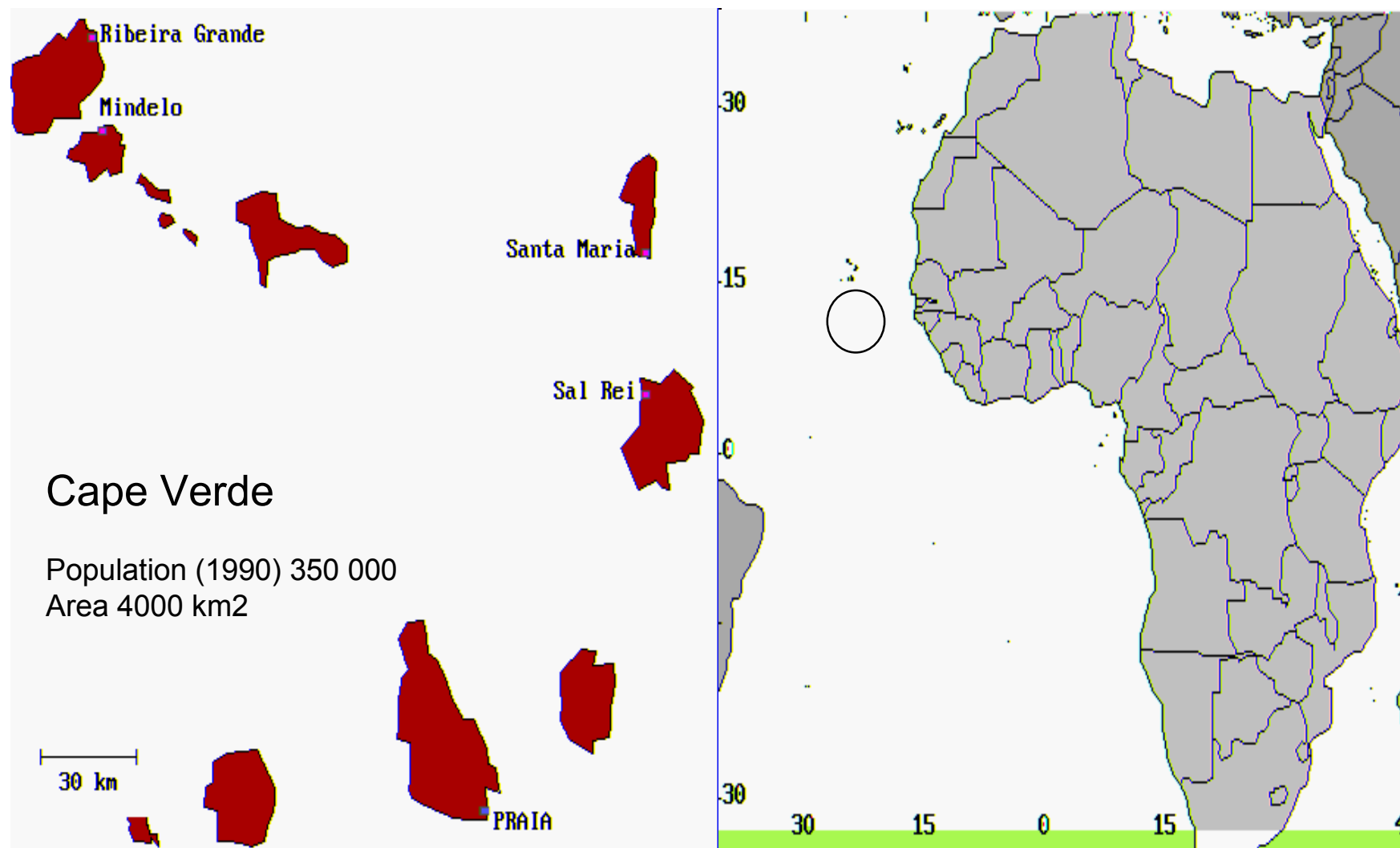
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Overview of the presentation

- *Introduction*
- *Overview of Wind Energy in Cape Verde*
- *Brief power system description*
- *Step 1 Wind Farm - experience and power system performance*
- *Step 2 Feasibility & initiation of further expansion*
- *Conclusions and recommendations*

Cape Verde



23-24 September 2002

Cape Verde - Status & experience
Sept 2002



Cape Verde

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Wind Energy in Cape Verde



Wind power was used to pump sea water into basins to evaporate in the sun, leaving the salt to be traded

The old water pumpers were made by wood, some say driftwood.

One of the old water pumpers are now on display in the island Sal

Wind Energy in Cape Verde I

Republic of Cape Verde

Based on information from ELECTRA

Location	Installation	Implementor	Donor/Investor	Working
Ponta d'Agua - Praia	2x55 kW Vestas - grid	INIT	UNSO/Danida	No
Assomada - Santiago	1x55kW Bonus - W/D	INIT	UNSO/Danida	No
Tarrafal - Santa	1x30 kW Lagerwey W/D	MDR	Holland	No
Mt. R. Juliao - Mindelo	10x30 kW Aeroman - grid	ELECTRA	Germany/KfW	20%
Santa Maria - Sal	1x75 kW Vestas - W/D	Morabeza Hotel	Morabeza Hotel	Yes
Palmeira - Sal	2x300 kW NTK - W farm	ELECTRA	Danida/Cape Verde	Yes
Mt. Montona - Mindelo	3x300 kW NTK - W farm	ELECTRA	Danida/Cape Verde	Yes *)
Mt. S. Felipe - Praia	3x300 kW NTK - W farm	ELECTRA	Danida/Cape Verde	Yes
Brava	1x150 NTK - W/D	Municipality	Germany/GTZ/Danida	Yes
Boa Vista	5x15 kW Vergnet - W farm	Municipality	France	Yes **)
Matão - Santiago	1x15 kW Vergnet - W/B	INERG	France	Yes

**) One temporarily down with gearbox problems; **) Performace to be enhanced by improved rotor*

Island systems energypenetration 14%, power penetration 35% without problems

Wind Energy in Cape Verde II

- **Small systems**
 - Several systems of prototype nature
 - Several not successful due to lack of skill of maintenance staff and immature technology
 - At least one successful: SR&R system, skilled operator, commercial system
 - Still activity in the area with new installations
- **Larger systems**
 - High penetration systems (14% annual energy coverage)
 - Grid connected wind turbines on diesel grids
 - No extra equipment
 - Satisfactory operating experience
 - Satisfactory power quality
 - In the process of increasing the installed capacity and the penetration level

Wind energy resources

annual average wind speeds and Weibull parameters at 30 m height

	U_{mean} (m/s)	Weibull - A (m/s)	Weibull - k
Praia - Mt. S. Filipe	7.8	8.9	3.62
Mindelo - Selada Flamengo	10.4	11.7	4.02
Sal - Palmeira	7.4	8.3	3.62

There IS wind in Cape Verde



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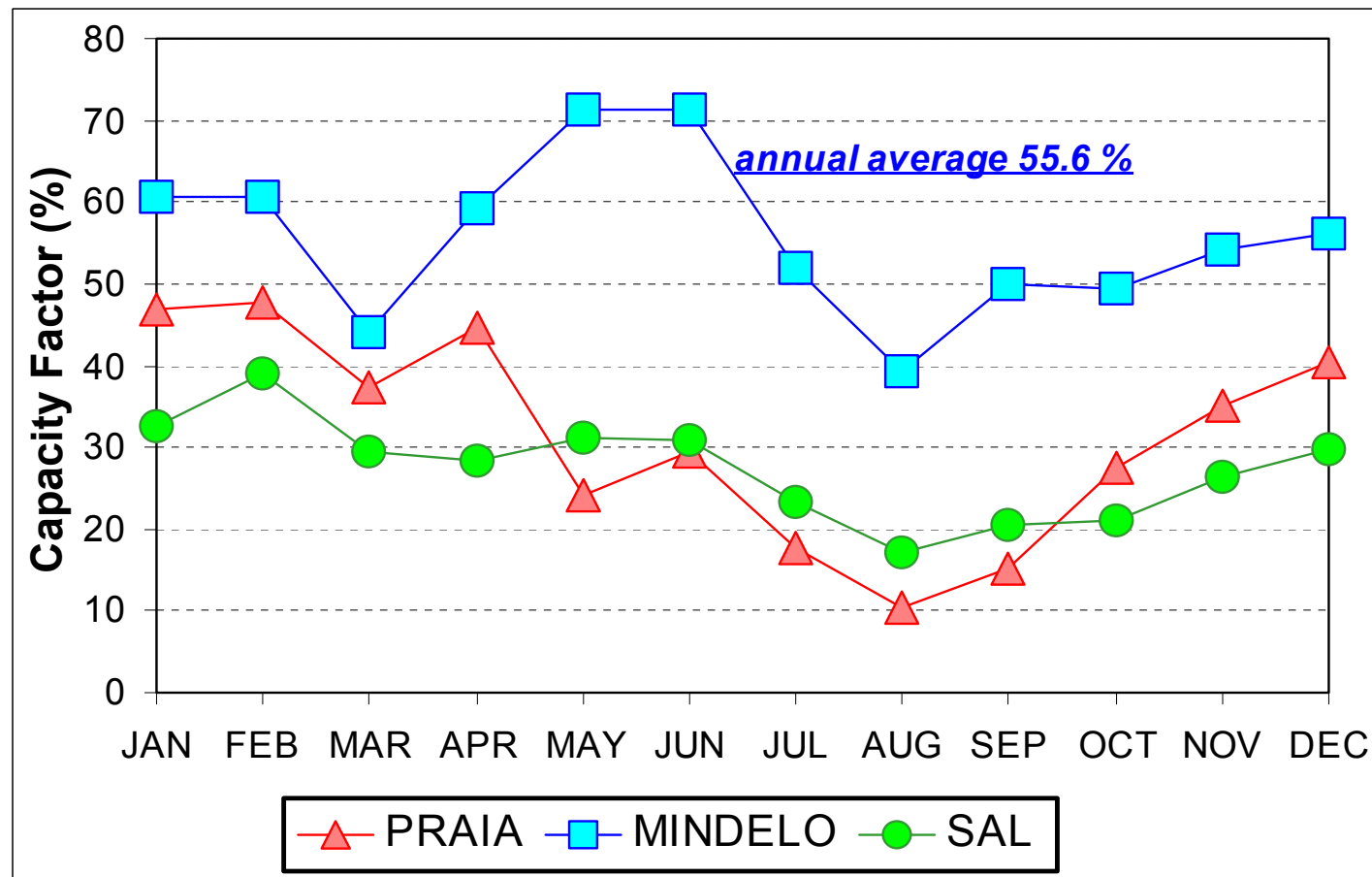
Key figures for Cape Verde (step 1)

Operation statistics for Step 1 Wind Farms averages 1995 - 1997

	Sal	Mindelo	Praia
Available diesel capacity (MW)	4	11	12
Diesel fuel type	gas oil	heavy fuel	gas oil
Installed wind turb. capacity (kW)	600	900	900
Avg. wind speed at hubheight (m/s)	7.4	10.4	7.8
Annual wind energy production (MWh)	1440	4390	2500
Annual power system load (MWh)	10120	32800	39870
Avg. wind energy penetration (%)	14	14	6.3
Avg. wind turb. capacity factor (%)	27	56	31
Annual diesel fuel savings (t)	340	970	615

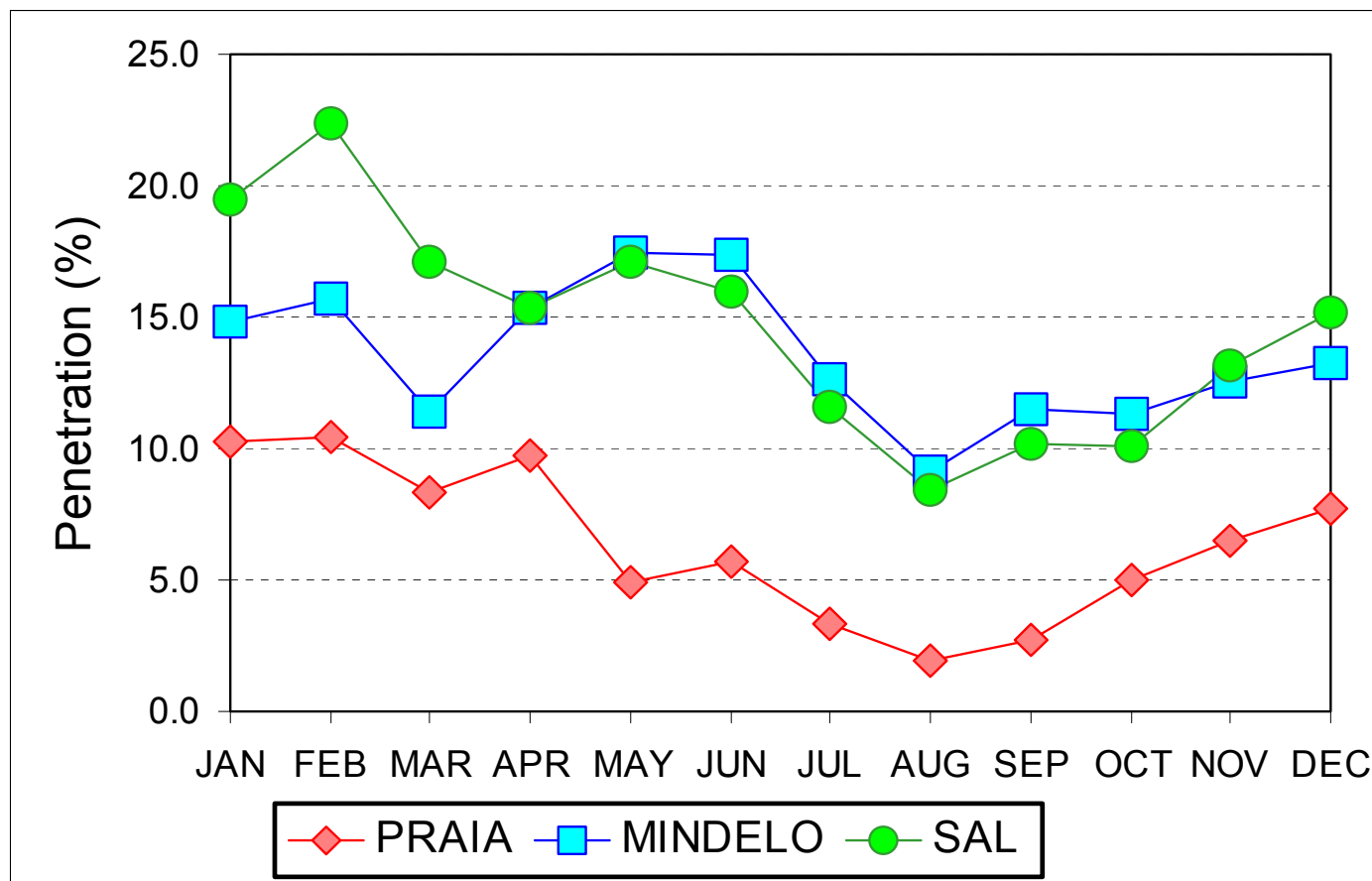
Average monthly capacity factor

Step 1 wind farms - 1995, 96 & 97



Average monthly wind energy penetration

Step 1 wind farms - 1995, 96 & 97



Wind turbines at Mindelo

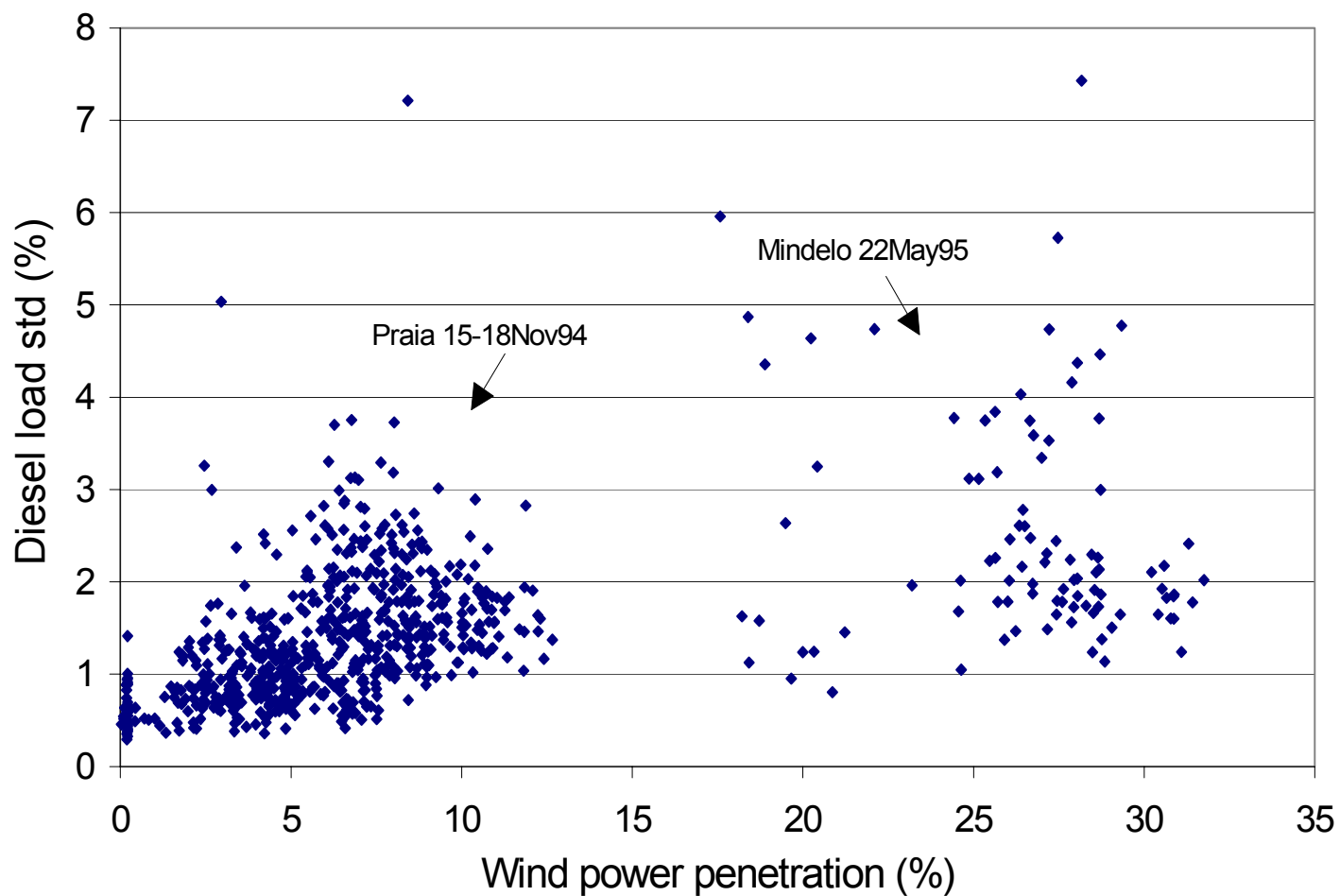


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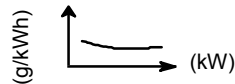
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Diesel load variations vs. wind power penetration



WINSYS modelling

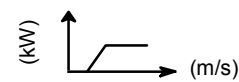
Plant specifications



Load pattern



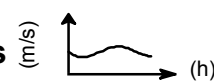
Power curve



Wind speed distribution

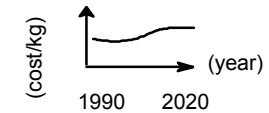


Seasonal and diurnal variations

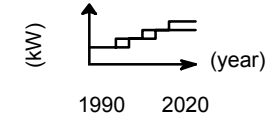


POWER PLANT

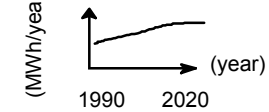
Fuel cost



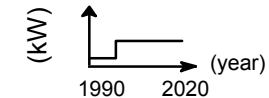
Plant development



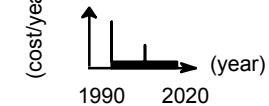
Consumer loads



Wind power capacity



WT investment and O&M

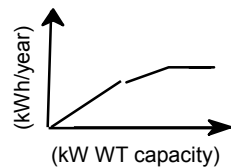


Load dispatching

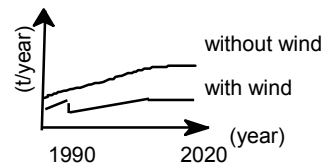
WINSYS

Unit commitment

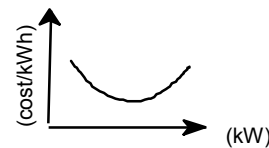
Wind energy output



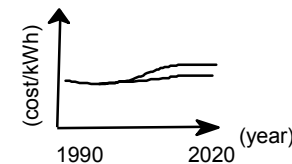
Fuel consumption



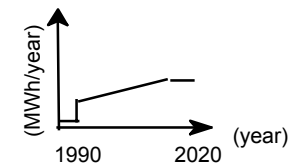
Optimum WT capacity



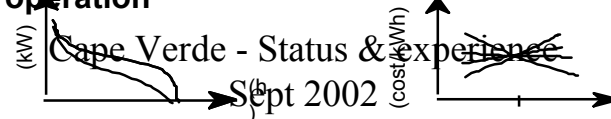
Cost of energy



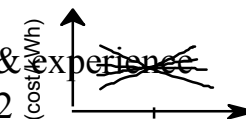
Utilized wind energy



System operation



Sensitivity analysis



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Validation of modelling

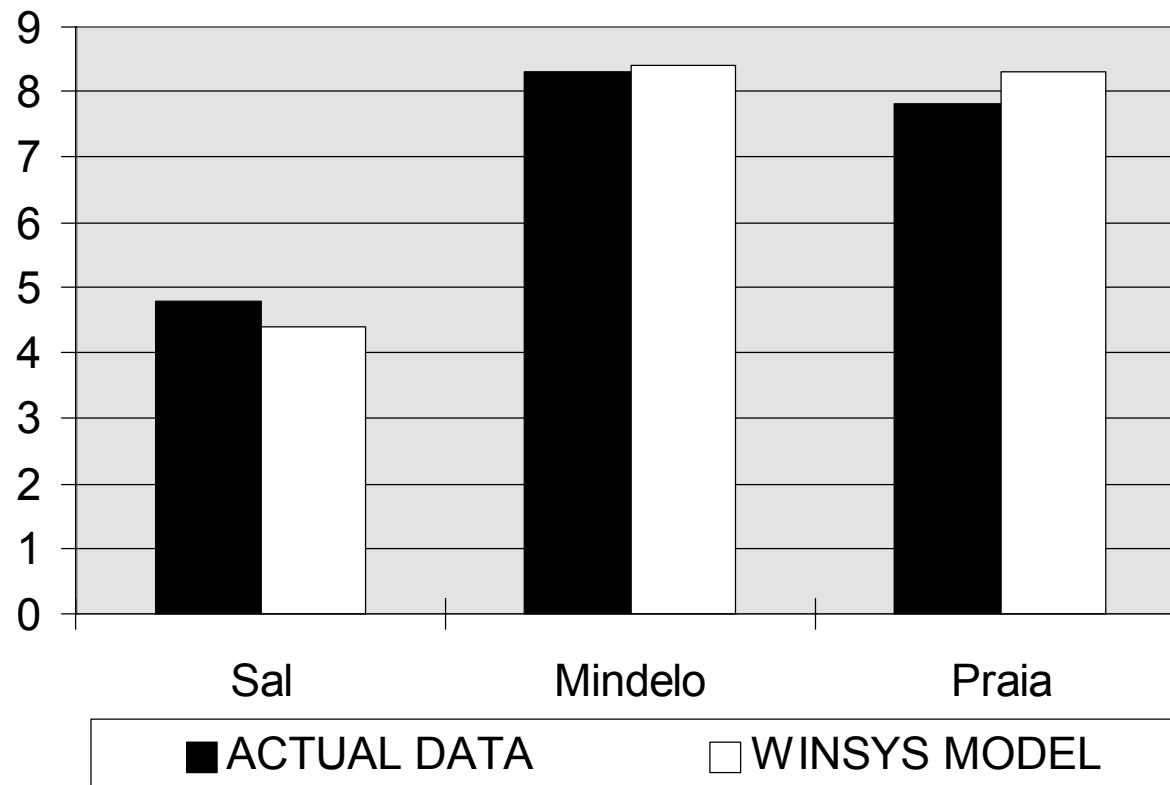


Figure 6 Comparison of actual fuel savings and result obtained by WINSYS modeling

Key figures for Cape Verde (step 2)

Feasibility study 1996, implementation decided 2000, project started 2002

		Sal	Mindelo	Praia
Existing Step 1 Wind Farm capacity (kW)		600	900	900
Recommended Wind Farm expansion (kW)		600	1200	1800
Production data for first year after installation (1997)	Step 2 util. output (MWh/year)	1366	4723	4146
	Step 2 fuel savings (t/year)	288	1098	968
	Step 1+2 total util. output (MWh/year)	2835	9303	6585
	Step 1+2 fuel savings (t/year)	598	2151	1542
	wind energy penetration (%)	24	30	18
Levelised production data for the 20 years lifetime (1997-2016)	Step 2 util. output (MWh/year)	1446	5863	4777
	Step 2 fuel savings (t/year)	306	1331	1046
	Step 1+2 total util. output (MWh/year)	2915	10473	7217
	Step 1+2 fuel savings (t/year)	617	2378	1581
	wind energy penetration (%)	16	19	7.5

Power system operation with Step 2 Wind Farms

	Praia	Mindelo	Sal
Step 2 wind farm capacity (kW)	1800	1200	600
Potential energy output (MWh/y)	5350	6744	1578
Annual utilized energy (MWh/y)	4777	5863	1446
Wind farm investment (USD/kW)	892	892	892
Other investments (USD/kW)	433	472	426
Total investment (USD/kW)	1325	1364	1318
O&M (% of wind farm investment)	2.5	2.5	2.5
Retrofit cost (% of wind farm invest.)	10	10	10
Salvage value (% of wind farm invest.)	0	0	0
Capacity credit (%)	24	44	18
Annual fuel savings (ton/y)	1046	1331	306
Diesel plant operation time savings (hours/y)	282	1306	82
Levelized production costs (USD/kWh)	0.062	0.034	0.066
Wind energy penetration - 1. year Step 1+2 (%)	18	30	24
Wind energy penetration - levelized Step 1+2 (%)	7.5	19	16

Conclusions

Evidence has been provided from Step 1 Wind Farms

- that wind power is feasible at wind energy penetration levels at least up to 25% with
 - a record high capacity factor of 55.6% as the average for 3 wind turbines for 3 years in Mindelo
 - average penetration for 3 wind farms in 3 years is 14%
 - maximum monthly wind energy penetration of 35% in Sal Feb. 1995
- that local power company and contractors can do local works
- that capacity building can be integrated in power company organization
- that modelling of power system performance (WINSYS) is possible

Wind farm expansion is feasible

- government policy and power company motivated and ready
- economic optimum wind farm size is higher than recommended project size
 - national economy / power company finances / IRR of project / consumer price
 - internalization of the external savings due to environmental benefits improve the economics of the proposed project by 40%
 - lack of international experience makes uncertainties and risks seem high
- international need for such pilot and demonstration projects